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## STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF THE UNIVERSITY OF MICHIGAN.

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## V. THE RELATION OF THE FLUCTUATIONS OF JUDGMENTS IN THE ESTIMATION OF TIME INTERVALS TO VASO-MOTOR WAVES.

By H. C. STEVENS, A. B.

1. *Introductory.* What relation, if any, exists between the fluctuations of the judgment of time intervals and vaso-motor waves as shown by a finger plethysmograph? There were several suggestive facts that pointed to such a relationship. The plotted results of practice experiments in the estimation of intervals, made during the previous year, showed a fairly well defined tendency to regularity in the rise and fall of the curve corresponding to the large and small deviations of the judgment from the normal interval. As the length of these waves seemed to agree generally in length with the longer vaso-motor waves, a possible causal connection between the two series naturally suggested itself. There was also another source of suggestion. In an investigation into the relation between the fluctuations of visual attention and vaso-motor waves, made by Slaughter [*Amer. Jour. of Psych.*, Vol. XII, p. 313], it was found that the vaso-motor waves corresponded identically with the attention waves. One might, therefore, suppose that any activity dependent upon attention in so high degree as the estimation of intervals would be conditioned very largely by the vaso-motor waves that accompany it. A careful review of the literature of Time Sense has revealed but one reference to our particular problem. Stevens [On the Time Sense, Mind, Vol.

XI, p. 393] in referring to the curve of plotted judgments notes "distinctly longer or primary waves" which appeared in all of his results, and which seemed independent of the length of interval. The length of these primary waves was from 0.6 to 0.9 minutes. These rhythmical variations he thinks are due to rhythmical changes in the "standard carried about in the mind" of the subject. In explanation of the variations he says, p. 401, "That this is connected with the rhythmical changes in the nutritive condition of the cerebral centers, as produced by vaso-motor rhythmical constriction of the arterioles, it would be rash to deny or affirm, or, perhaps, even to suppose." In addition to the problem as already stated, there are two other points that have come in for consideration, namely, the determination of the course of the constant error and the question of the validity of Weber's Law. There are also several minor points that will be discussed as they present themselves.

2. *Method.* The method of Average Error, as given by Külpe was used in this study. There have been numerous objections to this method as applied to the estimation of time intervals, chief of which is that of Glass [Phil. Stud., IV, p. 423, Kritisches und experimentelles über den Zeitsinn], who was the first to use the method extensively after Vierordt. In criticising the method he gives three sources of error that tend to increase the constant error beyond its true value. "Diese Zeit setzt sich aus mehreren Elementen zusammen, nämlich erstens aus jener Zeit welche vergeht, um von dem Urtheil dass die Fehlzeit der Normalzeit gleich sei, zu dem Entschluss übergehen, den Gang des Uhrwerkes zu hemmen: dazu kommt zweitens die Zeit, welche nötig ist, den Bewegungimpuls auszulösen und bis zum Muskel fortzupflanzen, und drittens wird noch Zeit verbraucht um den Hebel zu verrüchen, wenn diese letztere Zeit auch nur einen sehr kleinen Bruchtheil einen Secunde beträgt. Da alle Fehlzeiten um T zu gross sind, so wird der constante Fehler in Wahrheit gleich c—T und also $\Delta = c - T$ sein." And in another place he says that, at times, it may become as large as $\frac{1}{20}$th of a second.

If this criticism were valid, the method of Average Error would have to be abandoned for the estimation of time intervals, at least; but that it is not true is clearly proved by the work of F. Martius [Weitere Untersuchungen zur Lehre von der Herzbewegung. Zeitschrift für klinische Medicin, XV, p. 536] in an investigation to demonstrate the ability of a person to register the beats of the heart, precisely at the moment of hearing them, by the "akustischer Markmirmethode." In an earlier paper [Vol. XIII, same Journal], Martius attempted to ascertain what point in a cardiogram corresponded to a given sound in the heart cycle. This he attained by recording,

with a tap of the finger, the point on the curve which corresponded to a given sound in the heart beat. In criticism of his work it was maintained by some that the movement of the finger could not be made simultaneously with the sound impression; but that there would be a difference in time between the hearing of the sound and the recording movement equal to the person's reaction time.

Martius's second paper is a reply to that objection. With the result, as he shows, that one has the ability to record a continuous series of sound impressions practically without error; the error varies between 0.04″ and 0.017″, and is very often zero. Furthermore, it must be remembered that the normal heart beat is a variable stimulus and, undoubtedly, accounts for much of the error. It seems certain, therefore, that the threefold error mentioned by Glass cannot be considered well founded.

The advantages of the reproduction method lie (1) in the immediate results of the estimation which it gives: obviating the error of indirect sensible discrimination. (2) It allows a more complete surrendering of the subject to the rhythm of the sound impressions. (3) And most important of all for our own problem is the continuous series of judgments which it permits without interruption. Such a series was absolutely essential for the problem in hand in order to afford a direct comparison of the series of plotted judgments and the parallel series of vaso-motor waves.

3. *Apparatus.* The apparatus in its essentials consisted of the following parts: (1) A large smoked drum, driven by a half kilowatt electric motor. (2) A tuning fork of 50 double vibrations per second. This was kept in vibration by a storage battery. (3) A Meumann Time Sense Instrument. (4) A clock-work kymograph for recording the normal interval, pneumogram and plethysmogram. (5) A telegraphic sounder. (6)[1] A finger plethysmograph. (7) A Fitz pneumograph.

There were three separate electrical circuits connecting the different parts of the apparatus, a description of which will make the workings of the apparatus, as a whole, more clear. (1) From the Time Sense Instrument to the telegraphic sounder, and thence by a shunt to a time marker which wrote upon the clock-work kymograph. This circuit was supplied by a battery of two bichromate cells. The Time Sense Instrument is supplied with adjustable contacts [two, only, were used in the experiments] to which one pole of the battery was attached. The circuit was completed by the instrument itself. The contacts, above referred to, are insulated so that the cir-

[1] Amer. Jour. of Physiol., Dec., 1899.

cuit is made and broken by the revolution of a metal rod. [For a detailed description of the Time Sense Instrument see Meumann, Phil. Stud., IX, pp. 270-274.] There are five pulleys on the instrument so that rates of rotation varying between fairly wide limits could easily be obtained. This, together with the different positions of the electrical contacts upon the graded circle of the instrument, admitted of all intervals of the lengths desired. The shunt in this circuit from the sounder to the time marker on the kymograph was put in for the purpose of having some constant point of reference for the plethysmograms and pneumograms. Thus, the relation of any given normal interval to the plethysmographic or pneumographic curves could easily be obtained. And conversely any point in the blood volume or respiratory records could readily be referred to its exact place in the series of normal clicks. Furthermore, as the rate of the drum on which the normal was reproduced was much faster than the kymograph on which the plethysmograms and pneumograms were recorded, the record of the normal interval on the latter drum made the work of plotting the judgments taken from the former drum easy and accurate. (2) A circuit, supplied by one bichromate cell, from the telegraphic sounder to a time marker which wrote upon the large drum. There was also a shunt circuit from the sounder to a key beside which the subject sat, and by which he reproduced the normal interval by a slight tap of the finger. From this it will be seen that one and the same signal served both to record the normal interval and the subject's judgment. The key was provided with a spring which immediately broke the circuit after the removal of the finger. (3) A circuit from the storage battery to the tuning fork and a shunt circuit in which was a resistance box, connected the tuning fork with the second time marker which wrote the time in fiftieths of a second on the large drum just above the curve of normal interval and reproductions.

4. *Practice and Proceedure.* Of the six persons used in this experiment but two were practiced in the estimation of intervals, although all were experienced in psychological work. With the shorter intervals no preliminary practice was considered necessary, but with intervals 0.92″ to 7.24″ a period of practice immediately preceded the regular experiments. The hour of experiment was 1 P. M. The general proceedure was as follows: The subject was comfortably seated beside a table so that his fingers hung just above the key by which his judgment was recorded. The middle finger of the left hand was thrust into the plethysmograph which was suspended from the ceiling by a cord. In the later experiments [Intervals 2.40″— 7.24″] a pneumograph was attached to the thorax of the subject and adjusted to write

upon the clock-work kymograph. The telegraphic sounder, the clicks of which limited the normal interval, stood upon the same table and behind the reagent. The clock-work kymograph stood near by, beside which an assistant sat who attended to it and to the writing of the plethysmograph and pneumograph. The large drum, Time Sense Instrument, tuning fork and motor were in an adjoining room, all connections with the other parts of the apparatus passing through the wall. There was considerable noise made by the motor; but as it was in the nature of a muffled roar of constant pitch and approximately constant intensity it formed a background as it were, for the two clicks of the normal, without, in any way, tending to "drown them out." Hence it was neglected. Two seconds before the motor was started the preparatory "ready" was called out by the assistant attending that part of the apparatus. The motor was then started, and also the clock-work kymograph in the other room. As the revolving rod of the Time Sense Instrument passes the two contacts the sounder emits two sharp clicks. The subject is to press the key at the moment he thinks that a time has elapsed equal to that between the two clicks of the sounder. Then follows the same sequence of the normal clicks and the tap on the key as before until the drum has exhausted itself. The subject is then allowed to rest while the drum is again prepared and a like series gone through with. The method of single reproduction, as above described, was not adopted until after interval 0.72″. Before that, a method of multiple reproduction was followed. The normal interval was given as already described; but the subject instead of dating his judgment from the second click of the normal, made *two* taps upon the key as the limits of the time interval. There was thus left a time interval between the last click of the normal interval and the first tap of the reproduction. With very short intervals when the contacts were close together there remained a considerable interval before the revolving rod completed its revolution. To take advantage of this the subject was told to make as many reproductions of the normal interval as he conveniently could. This, however, proved detrimental, as some of the subjects persisted in "hurrying" the last judgments, although cautioned against it. The number of reproductions, therefore, was limited to three, before this method was abandoned for that first described. The effect of both multiple and single reproductions upon the length of judgment will be discussed more fully under the head of "Constant Error." With the change in the number of reproductions the two contacts of the time sense instrument were placed 120° apart, and not changed during the remainder of the work. All changes in the length of interval were effected by means of the

belts and pulleys. The result of this is, that the two normal intervals recur at precisely the same point, with reference to the complete revolution, for any interval. They thus tend to fall into a definite rhythm, which is kept constant for all the intervals worked with.

5. *Review of Meumann and Shaw and Wrinch.* Nichols [*Amer. Jour. of Psych.*, Vol. III] has given a complete review of the literature of the subject up to eighteen ninety-one. Meumann has reviewed the later work of Münsterberg and Schumann. We will give, therefore, a brief statement of the results of work that still remains unnoticed.

Meumann: The work of E. Meumann makes a turning point in the nature of Time Sense investigation. Previous to him the general character of the work was very decidedly quantitative. That this is the case is very clearly shown by only a slight acquaintance with the literature of the subject. For example, Kollert and Estel formulated mathematical laws for the course of the constant error. Mach investigated only the question of the validity of Weber's Law. And Fechner's criticism of Estel is very largely a discussion of methods and an interpretation of symbols. In contradistinction to work of this kind Meumann's point of view is pre-eminently qualitative. The object of his investigation is to show the effect of the different intensities of the limiting stimuli on the apparent length of intervals and the deceptions of judgments due to different kinds of "fillings."

There are three articles that deal directly with the estimation of intervals. (1) Beiträge zur Psychologie des Zeitsinnes [Phil. Stud., VIII, p. 431], which is a critical review of the literature of the subject, with particular attention to Münsterberg and Schumann. (2) [Phil. Stud., IX, p. 264.] A continuation of the former article, though this is wholly experimental. (3) Beiträge zur Psych. des Zeitbewusstseins [Phil. Stud., XII, p. 128], which is an experimental investigation into the effect of different kinds of fillings upon the estimation of intervals.

As a general result of the first experimental work [Vol. IX], Meumann concludes that the estimation of intervals falls into three classes. (1) Very short intervals up to 0.5″, the judgment of which is very largely determined by the quality—intensity nature of the limiting stimuli. (2) Intervals of medium length — 0.5″ to 3.0″—which are estimated directly. The only basis of judgment is the interval of time itself. (3) Long intervals — 3.0″ and above — which are estimated indirectly by the mediation of some organic function. Meumann also points out the fact that, if, in a series of clicks of equal intensities, one more intense than the others, is sounded, the interval

preceding it is apparently shortened. And, in general, it may be said that an intense limiting stimulus shortens the length of the interval preceding it, while a weak stimulus apparently lengthens it.

The general results of the second experimental article [Vol. XII] on the effect of the kind of filling on the estimation of a time interval are recapitulated on p. 247 in the concluding remarks from which I quote.

(1) "Unsere Zeitschätzung ist in hohem Masse abhängig von der Art der Ausfüllung der Zeitstrecken."

(2) "Diese Abhängigkeit äussert sich in ganz verschiedener Weise bei kleinen, mittleren und grösseren Zeiten."

(3) "Werden zwei different ausgefüllte Zeitstrecken miteinander verglichen, von denen die erste eine reizerfüllte, die zweite eine "leere" reizbegrenzte ist, so erscheint bei kleinsten und kleinen Zeiten die reizerfülte Zeit grösser wie die reizbegrenzte Zeitstrecke; bei grossen Zeiten tritt das Umgekehrte ein, die reizerfüllte Zeit erscheint kleiner wie die reizbegrenzte. Zwischen diesen beiden Richtungen der constanten Fehlschätzung unter dem Einfluss differenter Ausfüllung lässt sich fast immer eine Indifferenzzone nachweisen, innerhalb deren die different ausgefüllten Zeitstrecken gleich oder annähernd gleich erscheinen, innerhalb deren also weder Ueber—noch Unterschätzung einer von beiden Zeitstrecken herrscht."

(4) The influence of the number of filling impressions is more strongly marked with small times. With both visual and auditory stimulation the quality of overestimation increases with the number of filling sensations so long as they are not carried to a point of fusion.

(5) These rules hold good in whatever sense department the limiting stimuli are.

Shaw and Wrinch. The latest work that has been done in Time Sense is "A Contribution to the Psychology of Time," by M. A. Shaw and F. S. Wrinch [Univ. of Toronto, Studies Psych., Series No. 2, 1898-1900]. The work is divided into five sections. (1) An Historical Sketch of the Problem. (2) Theory of Time Estimation. (3) Experiments on the Lapse of time between the normal and comparative intervals. (4) Weber's Law and Time Estimation. (5) Reproduction of complex rhythmically-arranged groups of interval. This work undoubtedly suffers from the fact that a preconceived theory of time estimation is allowed to influence the experiments. The theory is, that there is in consciousness a "unit of time" which serves as the basis of all time estimation. This unit is equivalent to "the interval that lies between the short and

long groups, which has been found to be the most accurately estimated interval. It differs in length more or less in different individuals, but in all cases the constant error and mean variation are less as we approximate to it. Here, neither the limiting impression, which influences the judgment of the shorter intervals, nor the originally functioned content which influences the judgment of longer intervals, modifies the estimation to any marked degree. This remarkable fact, in connection with the estimation of intervals, that a more or less definite interval is estimated most accurately, and the further fact that as we depart from it in either direction errors arise in judgment, lead us to believe it to be the basis of the estimation of intervals in all cases—a temporal unit."

The justification for the theory is that it satisfies the demands "fundamental in the human mind" for "single principles," and also the "scientific demand for explanation by as few principles as are consistent with the facts." p. 18.

The experimental basis of the theory rests (1) upon the statements of Külpe, Meumann and others, that there is an interval of medium length—0.5″ to 3.0″—which is judged immediately. (2) That intervals less than the indifference time are overestimated. "This error in estimation seems to be due to the tendency of the unit to complete itself, it being the individual basis of estimation." (3) With the estimation of intervals longer than the indifference interval, the organic functions, already mentioned, serve, at least, as helps to judgment. "The explanation is not, however, that the content is the basis of judgment, but that the mind estimates intervals longer than the unit in terms of the unit itself, and that the unit or the multiple of it, is here represented by some regularly recurring organic function." (p. 20.) Although one would expect some individual variations of the unit, the differences between the length of the indifference interval as given by Külpe 0.5″—3.0″ and those determined by their own experiments are very wide. Thus they say K's "unit of time" is "probably not much above 225$\sigma$″. W's is 150$\sigma$ and S's 189$\sigma$. pp. 42-43.

The third section of the work, the experimental part, is to show the effect of a lapse of time between the normal and comparative intervals. In these experiments visual stimuli were used. The source of light was an incandescent lamp reflected by means of a mirror through holes bored in a band attached to the kymograph. The subject sat fifteen feet away, and received the stimuli through a telescope. As the drum revolved, intermittent flashes of light marked the interval. The intervals were reproduced by the subject "by means of a rigid steel wire, one end of which the observer held between his fingers and the other end passing round a pulley, was connected with

a pointer in contact with the paper." p. 126. The time was recorded upon the drum in hundredths of a second by means of a tuning fork. The average error, constant error and mean variation are worked out.

The results are quoted literally, p. 130. (1) The interval of half a second approximates to what has been called above the unit of time. . . . . Here, also, the effect of the pause is less than with intervals above it. The mean variation is the same for immediate [judgments] and "one minute," while the constant error is nearly the same for both. (2) With intervals above the unit of time the mean variation increases with the length of the pause. Sensibility decreases with intervals above the unit. (3) The constant error is practically the same throughout for "one minute" and "immediate." (4) After the lapse of half a minute the results are not regular: with the longest normal interval [153.66 hundredths of a second] the constant error is less than for the "immediate," but with the other normal intervals it is greater. The mean variation for a half minute is greater than for "immediate."

In the work upon Weber's Law and, incidentally, to show the effect of different intensities of the limiting stimuli, auditory stimulation was used. The normal intervals varied in length from 93$\sigma$ to 9150$\sigma$. I give the results below in two columns. (1) The length of normal interval and (2) the fraction of Weber's Law, *i. e.*, the "mean variation of the percentages of mean variations" are given in average for six to ten normal intervals. I quote the results of several subjects using the most favorable result, as in some cases two results are given.

| SUBJECT. | NORMAL. | M V OF %S M V'S. |
|---|---|---|
| K | 122– 257$\sigma$ | 0. 81% |
| | 93– 187$\sigma$ | 0. 82% |
| | 503–9050$\sigma$ | 0. 99% |
| W | 101– 187$\sigma$ | 0. 72% |
| | 131– 248$\sigma$ | 0. 67% |
| | 512–9825$\sigma$ | 0.727% |
| S | 107– 214$\sigma$ | 0. 62% |
| | 500–8870$\sigma$ | 1. 50% |
| B | 99– 254$\sigma$ | 1. 34% |

From these results the authors conclude that it speaks "very conclusively for the validity of Weber's Law." It should be pointed out, however, that part of the results, at least, were made from auditory stimulation of varying intensities and the remainder with visual stimulation. It seems rather remarkable that the results agree as closely as they do, considering the very different experimental conditions under which they were de-

termined. But it seems very doubtful if Weber's Law can be said to hold for the estimation of intervals on the evidence of results that show such wide variations as those just quoted. They cannot be compared, for regularity, with those of Glass [Phil. Stud., IV, p. 453], who is very reserved in pronouncing the law "ideal."

6. *Experimental.* Under this head there are three main points that come in for consideration (1) and chiefly, the relation of the fluctuations in judgment to vaso-motor waves. (2) The course of the constant error. (3) The validity of Weber's Law. The six subjects who served throughout the entire investigation were Drs. Pillsbury [Py] and Slaughter [Sr] and Messrs. Bair [Br], Bryant [Bt], Pearl [Pl] and myself [Ss]. The intervals used varied from 0.18″ to 7.24.″

Our problem, as has already been stated, was to show what relation, if any, exists between the plotted curve of judgments and the vaso-motor waves as shown by a finger plethysmograph. There were two methods used to establish this relationship. In the first place the two curves were compared directly. That is, the plotted curve of judgments was superimposed upon the vaso-motor curve, and the variations in the former curve compared with the waves in the latter. The two curves were, of course, of exactly the same length; and any point in one had a corresponding point in the other. The second method may be called the method of averages. The estimation curve was superimposed as before, the beginning and end of each curve exactly coinciding. Then the crest and trough of any well defined vaso-motor wave was projected upon the curve of judgments. The judgments in the latter curve which coincided with points in the crest of the vaso-motor wave were then averaged. And in the same way the judgments coinciding with the trough of the vaso-motor wave were averaged, and the average judgment for the crest compared with the average judgment for the trough. This latter method proved, on the whole, to give better results than the first described. Although, in general, the large fluctuations of judgment seemed to agree with changes in the plethysmogram, still there rarely appeared an exact coincidence of both waves in the same direction, for more than four consecutive fluctuations. While the method of averages could be applied at any point in the curve at which there was a well defined vaso-motor wave.

The method of plotting the judgments was as follows: On the abscissæ were laid off the normal intervals, for any given series, as a unit. This unit was constant, of course, for any given normal interval. The normal interval, as recorded on the clock-work kymograph, ranged from two millimeters at the beginning of the experiments to ten at the end. So that in

order to ensure exact coincidence of the plotted curve and the plethysmogram, the millimeter paper was placed upon the plethysmographic record and the series or normals, as recorded on that drum, marked upon the millimeter paper. The judgments as they were obtained from the other drum in fiftieths of a second—multiplied by two to give hundredths—were numbered to correspond to the series of normals as recorded on the plethysmogram. So that there was no chance for error in the direct comparison of the two series. The judgments in hundredths of a second, one millimeter to one one-hundredth of a second, were laid off on the ordinate. To save space some number which was less than the smallest judgment was subtracted from all judgments of a given series before plotting. Thus only the absolute fluctuations appeared in any plotted curve. By this means curves to the number of thirty-seven were obtained which had parallel plethysmographic records with well defined vaso-motor waves in some part of the ir course.

As a result of the direct comparisons we have selected six curves which show coincidences of the vaso-motor wave and the fluctuations in judgment. The normal intervals from which they were derived, vary in length from 0.4″ to two seconds.

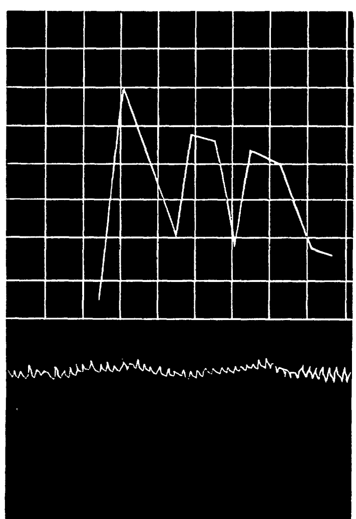

Fig. 1. Sr. subject. Interval N=0.66″. Curve reads from left to right.

The agreement of the three waves in each case of the two curves could hardly be bettered. The troughs of the curve of judgments exactly coincide with the troughs of the waves in the plethysmogram. Although the vaso-motor waves are not

extremely well marked, there is a very plain rise and fall nevertheless. On the other hand the curve of judgments—made up of ten judgments—is unusually regular. The specimens here given were taken both from intervals which were reproduced more than once and those only once. It would seem from a study of the plotted curves obtained, from both methods, that the number of reproductions was without effect on the fluctuations of judgment.

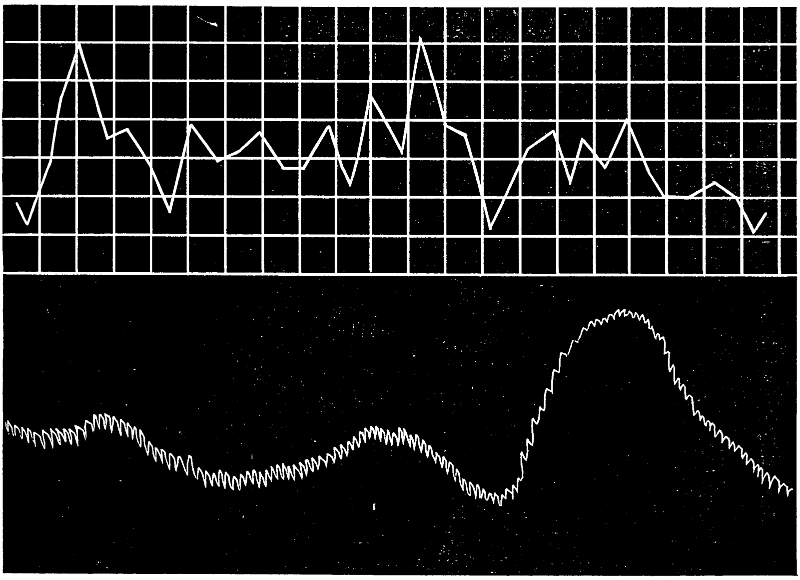

Fig. 2. Sr. subject. Interval N=0.77". Curve reads from left to right.

The curves here exhibited were derived from the last interval in the estimation of which multiple reproductions were made. There are three conspicuous rises in the curve of judgments with corresponding crests of the vaso-motor waves. In particular, the first two largest deviations in the curve of judgments seem to have well marked counterparts in the plethysmogram. It is doubtful if the third very large rise in the plethysmogram is a Traube-Hering wave. However, it was not due to external causes, and besides it agrees fairly well with a general, though fluctuating, rise in the curve of judgments.

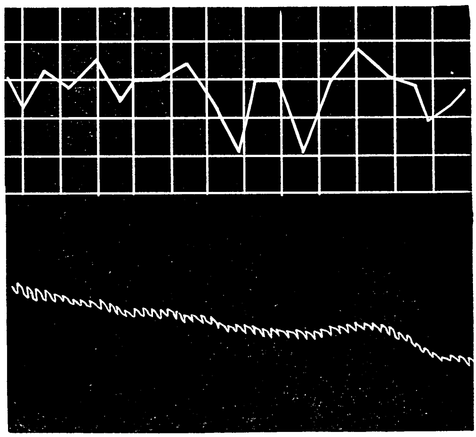

Fig. 3. Bt. subject. Interval 0.40″. Curve reads from left to right.

The interval from which these curves were derived was the first one of which single reproductions were made. The same deviation in the curve of judgments occur as in the others, although there is not much regularity. There are two well marked vaso-motor waves with corresponding rises in the curve of judgments. Between the two, however, is a short symmetrical rise and fall which agrees with a very slight rise in the plethysmogram between the two large vaso-motor waves before mentioned.

The plethysmogram in this case (see Fig. 4, p. 14,) is notable for the well marked and continuous series of vaso-motor waves. On the other hand, the variations in the curve of judgments are well marked but not very regular. In addition to the larger fluctuations there are many smaller ones which make it appear more or less broken. Of the eight vaso-motor waves that appear in this figure six have direct coincidences with the crests of fluctuations in the curve of judgments. On the other hand, the highest point in the estimation curve corresponds to the lowest of the plethysmogram. The remaining vaso-motor wave has no direct agreement with a rise in the judgments. This curve is also notable for the fact that it admits of direct comparisons for a longer period of time than any of the other curves.

As is shown in Fig. 5, p. 15, the fluctuations in the estimation curve are much larger than those previously exhibited. Although the agreement between the two curves can hardly be said to be exact, yet there is some coincidence, and what is more, the curve shows as many others did, though no direct comparison could be made, that where the changes in the ple-

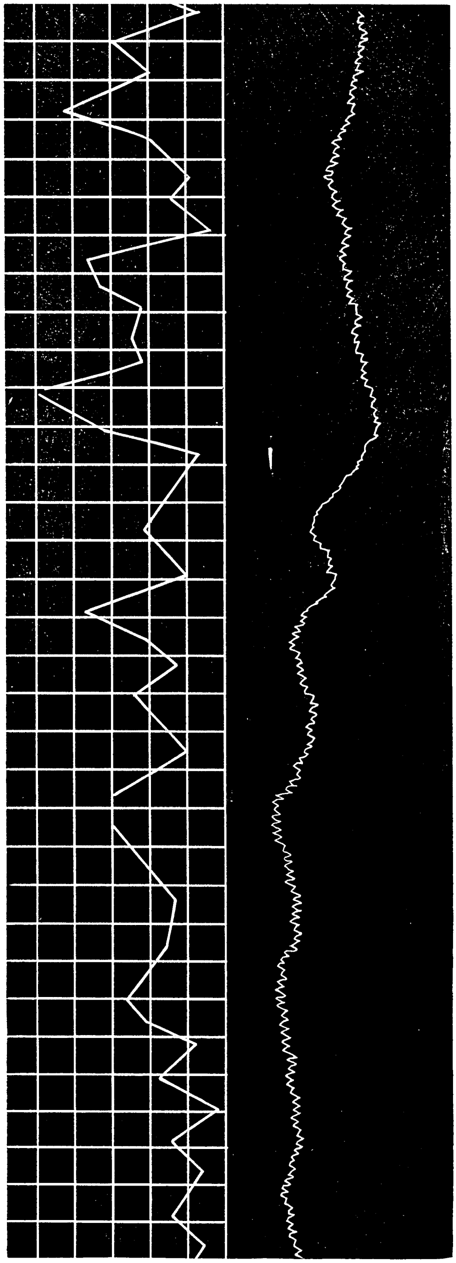

Fig. 4. Bt. subject. Interval 0.92″. Curve reads from left to right.

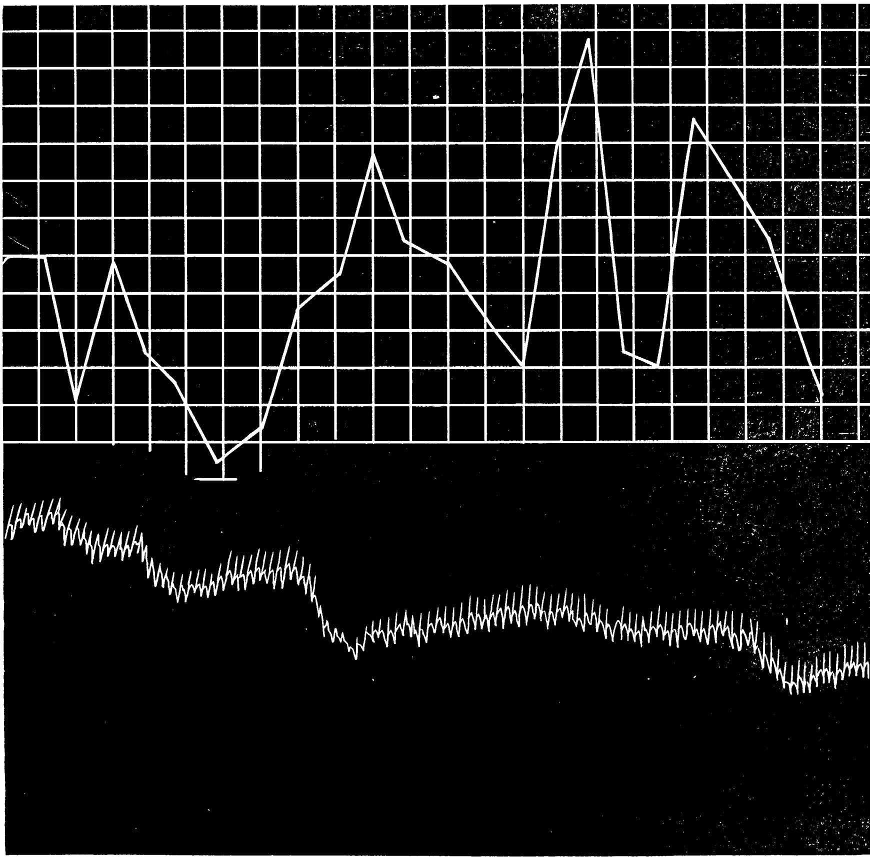

Fig. 5. Pl. subject. Interval 0.92″. Curve reads from left to right.

thysmogram are largest, that part of the estimation curve corresponding to it shows greatest variations. There is another point which this curve exhibits in common with those of the large intervals, that, as the intervals grow longer, the deviations of judgment from the normal interval grow larger.

There are only two vaso-motor waves in Fig. 6, p. 16, that can be said to correspond exactly to large deviations in the curve of judgments. Although, as was observed in the preceding curve, the fluctuations in estimation are largest with corresponding changes in the curve of blood volume.

As was said earlier in this article, the method of direct comparison does not yield as conclusive evidence as does the method of averages. And in either case, it must not be supposed that

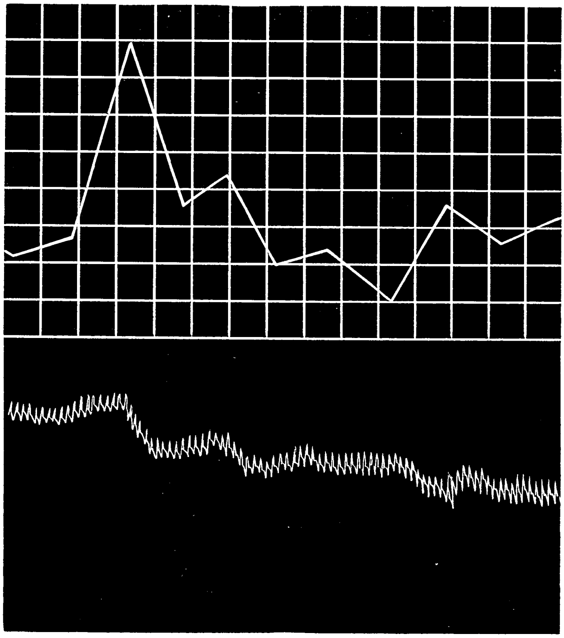

Fig. 6. Pl. subject. Interval [approximately] 2.00″. Curve reads from left to right.

the vaso-motor changes are the only factors at work in the estimation of intervals. If this were true one would expect invariable coincidences of the two series. As it is, there are a great mass of factors more or less obscure which must enter into the judgment of a length of time, and in view of this the absolute functioning of any one factor—as the vaso-motor changes in our case—is not to be expected. As other factors which would tend to influence the judgment may be mentioned the strain sensations of Münsterberg which are undoubtedly present; the emotions, surprise and expectation, of Schumann; the quality and intensity of the limiting stimuli; the objective and subjective rhythms of sound impressions. Then there are distractions of various sorts, and such factors as fatigue, practice, individual differences and varying experimental conditions. All of which tend to obscure any single factor.

In Table A are given the results of the method of averages. In the first column is given the number of the experiment. The second column gives the initials of the reagent; the third the length of the normal interval; the fourth the average of the judgments that correspond to the crest of the vaso-motor wave; the fifth the number of judgments that enter into a correspond-

TABLE A.

| No. | Reagent. | N. | Crest. | n. | Trough. | n. | Difference. |
|---|---|---|---|---|---|---|---|
| 1 | Pl. | 0.18 | .199 | 24 | .177 | 7 | +.022 |
| 2 | Ss. | 0.48 | .477 | 8 | .482 | 4 | —.005 |
| 3 | Pl. | 0.48 | .523 | 14 | .508 | 7 | +.15 |
| 4 | Pl. | 0.48 | .487 | 8 | .465 | 11 | +.22 |
| 5 | Py. | 0.66 | .771 | 12 | .700 | 7 | +.71 |
| 6 | Sr. | 0.66 | .822 | 7 | .678 | 7 | +.144 |
| 7 | Pl. | 0.66 | .722 | 13 | .657 | 8 | +.65 |
| 8 | Sr. | 0.72 | .896 | 9 | .790 | 5 | +.106 |
| 9 | B. | 0.40 | .360 | 3 | .280 | 2 | +.800 |
| 10 | B. | 0.40 | .430 | 2 | .330 | 4 | +.100 |
| 11 | Ss. | 0.40 | .445 | 2 | .350 | 2 | +.950 |
| 12 | Py. | 0.40 | .436 | 14 | .384 | 11 | +.520 |
| 13 | Pl. | 0.40 | .395 | 13 | .363 | 11 | +.320 |
| 14 | Py. | 0.70 | .730 | 9 | .630 | 14 | +.100 |
| 15 | B. | 0.92 | .861 | 11 | .828 | 7 | +.330 |
| 16 | Sr. | 1.32 | 1.26 | 9 | 1.16 | 6 | +.100 |
| 17 | Ss. | 1.32 | 1.26 | 8 | 1.13 | 10 | +.130 |
| 18 | Sr. | 2.40 | 2.23 | 2 | 2.00 | 1 | +.230 |
| 19 | Py. | 2.40 | 2.73 | 6 | 1.91 | 6 | +.640 |
| 20 | Pl. | 2.40 | 2.36 | 4 | 1.91 | 6 | +.450 |
| 21 | Py. | 2.40 | 3.46 | 3 | 2.32 | 4 | +1.140 |

ing average; the sixth the average judgments that occur at the trough of a vaso-motor wave; the seventh the number of judgments that enter into that average; the eighth the difference between the average crest and the average trough.

The last column in this table is the one for which it was designed. The difference between the average crest and trough shows only one case in which the latter exceeds the former, and that difference is but 0.005″ in favor of the trough. And on the other hand, the increase of the crest over the trough varies from 0.022″, the smallest to more than one second, the largest difference. While on the average the difference is very decided in favor of the crest.

This table shows much more conclusively the relation of the vaso-motor wave to the curve of estimation than is afforded by a direct comparison of the two curves. And it seems not unwarranted to conclude that the vaso-motor waves are, at least, one of the determining factors in the variations of the judgment in the estimation of time intervals. To attempt to ascribe all the phenomena observed in the estimation of intervals, to them would be absurd, and it is too much to demand an unexceptional coincidence in every case; yet that there is in at least 50% of cases an agreement between the two series seems from our experiments to be certain.

It will probably be noticed in Table A that the largest interval is 2.4 secs., although there were three other intervals

longer than this. The reason for that is that the plethysmograms showed hardly any vaso-motor waves. This was due, in all probability, to the unusually cold weather during which the last experiments were made, and also to the fact that the building was not heated. It is barely possible that their absence is due to the inhibitory effects of the longer intervals.

The difficulty that was experienced by most subjects with the longer intervals, and in particular, interval 5.45″ showed itself very plainly in the plotted curves. With the smaller intervals the amount of variation in either direction from normal the interval was comparatively small; but with longer intervals the uncertainty of judgment showed itself by the extremely large variations on both sides of the norm. In the last intervals this often amounted to two or three seconds.

*The Constant Error.* With reference to the constant error our own experiments as a whole divide themselves into two groups, all dependent upon the number of reproductions of the normal interval. In the first group [Intervals 0.18″-0.72″] there were, at first, five or six, and finally two reproductions made after each normal. But as this procedure proved detrimental by causing some of the subjects to hasten their judgments it was abandoned for the single reproduction method. In the second group [Intervals 0.40″-7.24″], therefore, but one reproduction was made for each presentation of the normal.

The effect of the number of reproductions upon the size of the constant error has received too little investigation, as yet, to speak with much certainty about it. As Nichols says, "New experiments seem needed for the tripartite relations between the sign of the Constant Error, the number or length of time the norm is given as a sample, and the number of reproduced judgments." Stevens [Mind, XI, p. 393], however, used the method of multiple reproduction, and has published the average judgment for each five seconds after the normal to the end of the series. The result is a very decided diminution of the size of judgment for each successive five seconds, as the series taken from Table II, p. 395, will show:

N= 1.44 (1) .960 (2) .830 (3) .740 (4) .710 (5) .677 (6) .610 (7) .590 (8) .480 (9) .360. This result is common to all of the tables as published. Nichols also used the multiple reproduction method, but has published only the first judgments after the normal. He says, however, that for one subject, L, the judgments are "unusually short throughout the experiments, and, in the curves, show themselves growing rapidly shorter and shorter to the end of the drum," while the "judgments of H. are unusually long throughout all his trials, and his curves go rapidly up throughout each drum." In our own experiments with the multiple reproduction there were, also, oppo-

site tendencies to be observed in different subjects. Thus Br. and Bt. showed a constant decrease with each reproduction, which very probably accounts for the small indifference time of Br. [0.46″] and the irregularities in Bt's constant error [Table IV]. While, on the other hand, the remaining subjects showed a constant enlargement of each successive judgment. Although the number of reproductions was, probably, too small to say finally what the effect would be.

From our own experiments the effect of the single reproduction may be inferred with more certainty. With but two exceptions all subjects show a positive error at 0.46″. One of the exceptions, Bt., gives a positive error at 0.58″. These intervals were estimated by multiple reproductions. On the other hand, all subjects but Py. [c=+.018] show a marked underestimation of the first interval [0.40″] in the second group. We may conclude, therefore, that the effect of the single reproduction is a decided lowering of the first indifference point.

The results of each reagent are given in a separate table. There are six columns given in each table. (1) The number of the interval in order of size. (2) The normal interval in hundredths of a second. (3) The constant error in hundredths of a second with the positive or negative sign prefixed to indicate an over or underestimation, respectively. (4) The average crude error. (5) The pure variable error. (6) The number of experiments made on each interval.

TABLE I. Py.

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | +.023 | 1.860 | .1035 | 506 |
| 2 | 0.34 | —.040 | 2.815 | .2843 | 400 |
| 3 | 0.46 | +.026 | 4.091 | .0889 | 333 |
| 4 | 0.58 | +.100 | 4.565 | .07871 | 119 |
| 5 | 0.66 | +.060 | 7.0671 | .10705 | 117 |
| 6 | 0.72 | +.027 | 4.509 | .06262 | 173 |

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.40 | +.018 | 3.488 | .08708 | 261 |
| 2 | 0.70 | —.028 | 4.441 | .06605 | 241 |
| 3 | 0.92 | —.017 | 7.516 | .0816 | 172 |
| 4 | 1.32 | +.18 | 14.434 | .1099 | 139 |
| 5 | 2.40 | +.235 | 31.1292 | .1296 | 61 |
| 6 | 3.70 | +.65 | 53.261 | .14391 | 65 |
| 7 | 5.45 | +.573 | 64.302 | .11673 | 40 |
| 8 | 7.24 | +.443 | 93.267 | .12882 | 32 |

The constant error, as shown by Py's results, is, in general, a typical instance of its course as exhibited in our experiments.

Yet there are some peculiarities that are not common to the other subjects. One striking exception is the negative constant error at 0.34″ in the first group. The reason for this, probably, lies in the fact that interval 0.34″ was the first one used in the beginning of the investigation. Hence, the lack of practice may account for it. Nichols also points out that any "slight nervousness or excitement of the subject shortens the judgment." This, too, may have had something to do with it, The change of sign of the constant error at interval 1.32″ in the second group is also somewhat anomalous. But as the overestimation after this is constant the cause will have to be ascribed to some individual peculiarity.

TABLE II. Br.

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | + .004 | 1.5803 | .08834 | 371 |
| 2 | 0.34 | + .025 | 1.987 | .05840 | 422 |
| 3 | 0.46 | — .045 | 2.730 | .05932 | 509 |
| 4 | 0.58 | — .011 | 3.524 | .05990 | 129 |
| 5 | 0.66 | — .049 | 4.2306 | .06409 | 109 |
| 6 | 0.72 | —1.02 | 3.893 | .05406 | 132 |

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.40 | —.035 | 4.079 | .1019 | 244 |
| 2 | 0.70 | —.068 | 4.792 | .06827 | 227 |
| 3 | 0.92 | —.073 | 4.823 | .05237 | 183 |
| 4 | 1.32 | —.013 | 12.093 | .0916 | 139 |
| 5 | 2.40 | —.117 | 17.350 | .07229 | 40 |
| 6 | 3.70 | +.02 | 47.999 | .12973 | 44 |
| 7 | 5.45 | +.160 | 254.570 | .46706 | 35 |
| 8 | 7.24 | —.30 | 63.030 | .08705 | 34 |

The small indifference time of Br. [0.46″] in the first group is probably due, as I have already said, to the constant tendency to decrease the size of each successive reproduction. Yet it may be wholly normal as the indifference time as given by Külpe varies between 0.5″ and 3.0″. The sign of the constant error in the second group changes somewhere between 2.4 secs. and 3.70″. It also, again, changes signs at 7.24 secs. What this last change is due to I am at loss to know.

The points to be noted in the course of the constant error in Table III, p. 21, are the negative sign of the error at 0.72″ in the first group and the small underestimation of the first interval in the second group. There is also another indifference point between 2.4″ and 3.70″. From there on the overestimation is very large.

TABLE III. Ss.

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | + .039 | 1.622 | .09011 | 371 |
| 2 | 0.34 | + .027 | 1.769 | .0502 | 126 |
| 3 | 0.46 | + .011 | 3.312 | .07199 | 184 |
| 4 | 0.58 | + .017 | 5.1965 | .08959 | 98 |
| 5 | 0.66 | + .232 | 12.55 | .18999 | 129 |
| 6 | 0.72 | —1.01 | 6.660 | .09249 | 134 |

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.40 | — .002 | 3.431 | .08617 | 114 |
| 2 | 0.70 | — .087 | 5.086 | .07265 | 269 |
| 3 | 0.92 | — .042 | 4.375 | .0475 | 172 |
| 4 | 1.32 | — .152 | 8.3852 | .06396 | 91 |
| 5 | 2.40 | — .267 | 18.942 | .0812 | 32 |
| 6 | 3.70 | + .886 | 68.536 | .18532 | 60 |
| 7 | 5.45 | +1.5 | 131.08 | .23984 | 36 |
| 8 | 7.24 | +1.02 | 111.906 | .15456 | 33 |

TABLE IV. Bt.

| No. | N. | c, | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | +.008 | 1.2022 | .06678 | 536 |
| 2 | 0.34 | +.040 | 2.180 | .06411 | 22 |
| 3 | 0.46 | —.038 | 3.100 | .0674 | 254 |
| 4 | 0.58 | +.015 | 3.6285 | .06255 | 123 |
| 5 | 0.66 | —.053 | 3.1134 | .0471 | 132 |
| 6 | 0.72 | —.066 | 4.1562 | .05272 | 110 |

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.40 | — .011 | 6.009 | .1502 | 237 |
| 2 | 0.70 | — .046 | 3.959 | .0597 | 211 |
| 3 | 0.92 | — .060 | 4.4365 | .04822 | 177 |
| 4 | 2.40 | — .080 | 17.452 | .0745 | 73 |
| 5 | 3.70 | + .020 | 47.13 | .1135 | 45 |
| 6 | 5.45 | +1.23 | 85.554 | .14461 | 45 |
| 7 | 7.24 | + .43 | 108.378 | .14969 | 31 |

The constant error as derived from Bt's results shows considerable variation in the first group; the first change of sign at 0.46″ and also the large negative error at 0.66″ are in all probability due to the multiple reproduction. Yet the positive error at the interval [0.58″] between these two seems to contradict this, as it was obtained by the same method. The constant error in the second group agrees completely with the results of the other reagents, showing the underestimation from

0.40″ up to 2.40″ and an overestimation from 3.70″ on to 7.24″.

TABLE V. Pl.

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | + .021 | 1.3355 | .07419 | 346 |
| 2 | 0.34 | + .055 | 2.0537 | .06035 | 186 |
| 3 | 0.46 | + .034 | 2.7260 | .05925 | 199 |
| 4 | 0.58 | + .065 | 3.595 | .06197 | 121 |
| 5 | 0.66 | + .037 | 3.7449 | .05381 | 134 |
| 6 | 0.72 | +2.03 | 8.0132 | .10828 | 79 |
| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
| 1 | 0.40 | —.022 | 2.620 | .0655 | 247 |
| 2 | 0.70 | —.1005 | 6.506 | .09291 | 230 |
| 3 | 1.32 | —.200 | 12.546 | .09650 | 64 |
| 4 | 2.40 | —.255 | 24.329 | .10136 | 70 |
| 5 | 3.70 | +.59 | 54.539 | .1475 | 43 |
| 6 | 5.45 | +.48 | 46.075 | .08453 | 42 |
| 7 | 7.24 | +.60 | 46.969 | .06483 | 24 |

The constant error in Pl's results in the first group show very decided overestimation in every case, and particularly at 0.72″. This is probably due to the fact that Pl. was one of the subjects who showed successively larger reproductions after the normal. The second group agrees in general with all of the others, showing an underestimation of the interval up to 3.70″, and from there on a very decided overestimation.

TABLE VI. Sr.

| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
|---|---|---|---|---|---|
| 1 | 0.18 | +.053 | 1.599 | .08832 | 274 |
| 2 | 0.46 | +.063 | 3.7806 | .08218 | 176 |
| 3 | 0.58 | +.078 | 4.7255 | .08147 | 126 |
| 4 | 0.66 | +.117 | 4.9906 | .06861 | 125 |
| 5 | 0.72 | +.055 | 6.1345 | .08289 | 126 |
| No. | N. | c. | $\Delta m$ | $\frac{\Delta m}{N}$ | n. |
| 1 | 0.40 | —.0325 | 4.043 | .1009 | 246 |
| 2 | 0.70 | —.204 | 6.629 | .09445 | 233 |
| 3 | 2.40 | —.19 | 18.038 | .07515 | 100 |
| 4 | 5.45 | —.17 | 50.034 | .09273 | 43 |
| 5 | 7.24 | +.40 | 58.453 | .08073 | 33 |
| 6 | .... | ...... | ...... | ...... | ... |
| 7 | .... | ...... | ...... | ...... | ... |

Sr. like Pl. was one of the reagents who gave successively

larger reproductions, and the large overestimation of all of the intervals in the first group is very probably due to that fact. In the second group the change of sign of the constant error does not occur until 7.24″. This may have its origin in the lack of reacting to some of the longer intervals, as no results were obtained from him on intervals 0.92″, 1.32″ and 3.70″. So that a considerably longer time elapsed between his experiment days and those of the other subjects.

The general course of the constant error shows an overestimation [in the first group] of intervals up to 0.72 seconds. Then an underestimation [in the second group] from 0.4″ to 2.4″, from which interval on the sign of the constant error is reversed, with an increasingly large overestimation. These results agree very closely with those obtained by Mehner [Phil. Stud. XI, p. 546] by the method of Average Error. The following table gives the normal intervals and the corresponding constant errors as obtained by him. p. 594.

| N. | C. |
|---|---|
| 0.70 | +.09 |
| 0.80 | —.025 |
| 1.00 | —.068 |
| 1.50 | —.1117 |
| 2.10 | —.035 |
| 3.50 | +.01 |
| 5.00 | +.0375 |
| 6.00 | +.94 |

With the exception of a disparity between the sign of the constant error for 0.70″ the two results agree very harmoniously. Mehner's second indifference point lies between 2.10″ and 3.50″, and our own between 2.40″ and 3.7″. Just at what point the sign changes would be impossible to conclude from either set of experiments. But, taken together, they would show that it lies between 2.4″ and 3.5″.

*Weber's Law.* The validity of Weber's Law for the estimation of intervals of time is still a moot point. There is, perhaps, an equal division of opinion among the many investigators who have discussed this problem. The results of Glass [Phil. Stud., IV, p. 453] as given in Table III show a greater constancy of the fraction of Weber's Law than any that I have seen. Of the results obtained from thirty-four intervals, in twenty-nine cases the first two figures are four hundredths, and in the remaining five cases five hundredths. From these results Glass concludes that Weber's law in the Province of Time Sense is to be considered an Ideal Law as Mariotte's Law is in Physics.

From our own results it would be very difficult to conclude

in favor of the law. For, not only are there many irregularities, but also there seems to be an increase in the value of $\frac{\Delta m}{N}$ as the larger intervals are reached. Manifestly, if such is the case, one could not maintain that the law held. There is, however, a peculiarity that should be pointed out. Namely, that each subject seems to have an individual value of $\frac{\Delta m}{N}$ from which variation arise in either direction. In the case of Br. it is in the neighborhood of .0500 or .0600, while with Sr. it is most nearly constant at .0800. And it is in Sr's results, in general, that there seems to be an approximate constancy of the value of the average pure error.

*Respiration as an Aid to Estimation.* According to Münsterberg's theory of time estimation, the strain of muscles during respiration is made the basis of time estimation. We have endeavored to ascertain by the introspection of reagents just what part, if any, the strain of respiration does play. A pneumograph tracing was taken in the experiments from interval 2.40″ to 7.24″. The tambour was adjusted to write just over the series of normal intervals as obtained on the kymograph. So that by projecting the normal interval upon the respiration curve the phase of breathing in which the subject was when the limiting stimuli were given could easily be determined. And, likewise, the phase of breathing in which the judgment was made could be determined.

It may be stated generally from the introspection of the reagents that there was considerable tendency, and, in many cases, actual use of the respiration as a measure of the longer intervals. Thus, Br., Interval 3.70,″ says he "found himself estimating the interval by respiration, and could not keep his attention off from it." He expired on receiving each of the limiting impressions. Also with the interval next higher, 5.45,″ Br. reports that he intended to make his estimate by breathing. With the last interval, 7.24″, the same subject noticed a similar effect. He tried hard to keep attention off his breathing, but could not avoid reacting at expiration. Bt. reports that for interval 5.45″ he estimated entirely by respiration. But for interval 3.70″ and 7.24″ he did not use it, although in both of these intervals he used other means. With intervals 3.70″ and 7.24″ Py. reported the presence of strain sensations. With the shorter interval he noticed a tendency to estimate in terms of strain of respiration. With interval 5.45″ he observed that he "could not estimate definitely in strain sensation; but tended to do so," he "noticed that his judgment fell in the same phase of respiration as the normals." For interval 3.70″ Pl. reported that "during the first series all attention was given to estima-

ting the interval by relating it to breathing. There was a very good relation between the normal interval and a certain number of inspirations and expirations ("two inspirations and one expiration equal to the normal interval). Then the estimate of the interval was made from this relation." Pl. was the only reagent who had any tendency to estimate the interval by counting. In one case, interval 3.70″, he filled the interval with a rhythmical repetition of "one" "two" "instead of a consecutive count during the whole interval." Again, with interval 7.24″, he says that "the judgments were made by counting consecutively up to nineteen or twenty." Sr., interval 5.45″, is peculiar in being the only subject to report the presence of the strain of abdominal muscles in consciousness. He says that the strain sensations were most conspicuous at the end of the normal interval and at the moment of his reaction.

By projecting the point, indicated on the clock-work kymograph by the first click of the normal interval, upon the respiratory curve, the relation between the two could be plainly brought out. And almost universally for any given series, the relation between the two remained constant throughout. That is, for example, if the first click of the normal interval enters at the crest of the respiration curve, between the expiration and inspiration, the first click of the next normal interval will enter at precisely the same point with perhaps five or six complete phases intervening. If the point of entrance is shifted then there is a corresponding shift of the point of entrance of the next normal. These relations held generally for all subjects during the intervals in which the pneumograph was used.

The point in the respiratory curve at which the judgment was made, has been determined for three subjects only, in one interval [3.7″]. Time would not allow longer investigation. As has been said, the normal interval was obtained upon the kymograph, in addition to the tracing upon the revolving drum, and of course the time of the interval was known. Hence, to obtain the time of rotation of the kymograph, the distance in millimeters, between two normal clicks was divided into the lengths of the interval, which gave the length of time per millimeter. Then, dividing the judgment in time, by this quotient, gave the length of judgment in millimeters which could easily be measured from the second click of the normal interval and the point in which the judgment was made, accurately determined. This point, projected upon the respiratory curve gave the phase of breathing in which the judgment was made.

This point, as determined in the three cases alluded to, shows an approximate constancy for any given series. For example, in Pl's case, the judgment is made in two series at

the trough of the respiration curve, between the phases of inspiration and expiration. This holds, generally, throughout; but if the point is changed it remains constant for the remainder of the series. Likewise, with Py. and Br. The judgment in Py's case falls at the crest of the respiratory curve between the phases of expiration and inspiration. But, in general, it remains constant throughout any one series. Br's judgment is made at the beginning of the inspiratory phase. And like the others, it is generally constant.

It cannot be concluded from these three cases that the relations observed here hold good for other subjects or for other intervals.

## Summary of Results.

1. The vaso-motor wave coincides, in at least 50% of the cases, with the fluctuation in the judgment of an interval of time.
2. For intervals above 3.7 secs. the strain of respiration may be used as an aid to estimation.
3. The method of single reproduction tends to lower the indifference point.
4. Intervals below 0.72″ [0.40″] are overestimated. From that interval to 2.4 secs, the intervals are underestimated. From 3.7″ to 7.24 secs. the intervals are overestimated.
5. Weber's Law does not hold for the estimation of time intervals.
6. There is no special Time Sense in consciousness; but our judgment of time is mediate, depending upon organic processes, of which the changes in blood volume is one of the more important.

## Conclusions.

It has been stated in the summary that the vaso-motor wave in, at least, 50% of the cases, coincides with the fluctuations in judgment of a time interval. While this is not a predominating per cent. of all cases, still it may be taken as a positive answer to the problem as stated at the outset. It should be remarked here that the best coincidences and, in fact, all of those exhibited in this paper, occurred on intervals of time from 0.4″ to 2 seconds in length. This is borne out by many of the curves not published. This would seem to indicate some sort of connection between the indifference time or "unit of time" and the vaso-motor waves. But just what the relation is can not be determined from these experiments. The general length of the vaso-motor wave, as shown in our results, varied from five to twenty seconds. The general length of the fluctuation in judgment likewise varied from six to thirty-five seconds. On the whole there seemed to be a gradual increase in the length

of both vaso-motor wave and fluctuation of judgment as the length of the interval was increased. But, in any case, the two kinds of variations stay fairly well together.

In attempting to determine the part played by the vaso-motor wave and respiration, in the estimation of intervals, there seems to be an obvious line of distinction between the two processes. As has been said, the best and most frequent coincidences of vaso-motor curve and curve of judgments occurred at intervals of 0.4″ to 2.0″ in length. On the other hand, it was not until interval 3.7″ had been reached that subjects began to report any tendency to use respiration as a measure of the interval. Bearing these two facts in mind, it would seem that each function plays a more influential part according to the length of the interval estimated. For intervals of medium length [0.4″—2.0″] it would appear that the vaso-motor changes, of all factors, predominated. While for longer intervals [3.7″—7.24″] the respiration is, apparently, of greater influence. Yet it must not be inferred from this that the vaso-motor changes and respiration are the only factors involved in the estimation of intervals. We can only say that they were most conspicuous in our experiments. As to muscle strains alone, apart from respiration our experiments offer but little evidence. In fact they were reported by but one subject, and that for only one interval. So that their function, if any they have, must remain undecided by these experiments.[1]

[1] I wish, here, to thank the gentlemen who kindly gave their time to serve as subjects in this investigation. Particularly, Mr. J. H. Bair, who acted as assistant. It was due to his careful work that the plethysmograph yielded the good results that it did.